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AUTOMATIC DATA PROCESSING TECHNIQUES FOR GRAPHIC-DATA DISPLAY, GENERATION AND ANALYSIS

Interim Technical Report

1 September 1976 - 31 August 1977

for Grant AFOSR 76-2937

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Prepared for

Directorate of Mathematical and Information Sciences
Air Force Office of Scientific Research
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ABSTRACT

This is an Interim Technical Report describing research carried out under Grant AFOSR 76-2937 during the 12-month period 1 September 1976 - 31 August 1977. The overall objective of the research program is to make significant improvements in the state of the art relating to the extraction, representation and computer interpretation of line drawing data. Specific tasks during the reporting year were concerned with (1) the reconstruction of solid-object descriptions from multiple photographic projections, (2) the development of programs for the removal of "hidden lines" from the projection of both planar-faced and quadric-surface objects, (3) the design of a generalized chain coding scheme for the compact and precise description of map data, (4) the development of a line-drawing processing language (CHAP), and (5) an investigation into some new approaches to scale- and orientation-independent shape classification.

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AUTOMATIC DATA PROCESSING TECHNIQUES FOR GRAPHIC-DATA DISPLAY, GENERATION AND ANALYSIS

1. SUMMARY OF RESEARCH

1.1 General

This Interim Technical Report describes progress on the research program being carried out under Grant AFOSR 76-2937 during the 12-month period 1 September 1976 - 31 August 1977. The general objective of the program is to advance the state of the art of computer processing of line-drawing data. In terms of familiar disciplines, the work bridges activities commonly classified under pattern recognition, image processing, and computer graphics. Emphasis is on the development of efficient computer techniques for processing line-drawing data, the extraction of such data from image arrays, its compact representation, its analysis and manipulation, and its classification (pattern recognition). Areas of application are all aspects of map data encoding and processing, the automatic generation and analysis of terrain contour maps, the reconstruction of 3-dimensional object models from multiple photographic projections (using line -drawing analysis techniques), and the detection and classification of man-made features in aerial photographs.

During the past year, the research effort was focussed on five distinct tasks. Each of these is briefly summarized in the following sections. A number of technical reports and journal articles were published during the past year, describing the work in considerable detail. Abstracts of these are given in the section titled PUBLICATIONS.

1.2 Scene Reconstruction from Multiple Photographs

During the past year a major effort was devoted to the problem of constructing computer models of three-dimensional bodies from multiple photographic projections. The method used, which was developed over a number of years, presumes that line drawings are first generated from the photographs and that the information from the multiple line drawings (which may be imperfect due to shadows, glare, poor illumination, or computer limitation) is then combined to obtain a three-dimensional computer model of the scene. The work was completed during the reporting period with the achievement of the stated objectives and the publication of a doctoral dissertation [11]. Two papers based on this work were published during the past year [7,8], a third paper has already been accepted for publication [9], and a fourth has been submitted [10].

1.3 Programs for Hidden-Line Removal

During the past year work was completed on the testing, evaluation and documentation of two quality programs for the removal of the hidden lines in the projections of three-dimensional solids. The work had been requested by the Structures Division, Flight Dynamics Laboratory, Wright-Patterson AFB. One of the two programs, PDRAW, is applicable to planar-faced bodies and is based on the Loutrel algorithm [12]. This program has now been checked out for the following computers systems: CDC 6600, UNIVAC 1110, IBM 360, PDP-11, and ADAGE AGT/30. A user manual for the program was published [1].

The second hidden-line removal program is applicable to quadric-surfaced bodies and is based on the Woon algorithm [13]. The program is able to generate true projections (perspective and orthographic) of complex objects bounded by quadric-surface patches and to delete the hidden lines. Since a plane can be regarded as a degenerate quadric surface, the algorithm will, of course, also handle objects bounded by planar faces; however, since it is considerably more complex than the Loutrel algorithm, it should only be used when the objects of interest have one or more curved surfaces. The program, QUADRAW, was completed and thoroughly tested during the past year. Implementations now exist for the following computers: CDC 6600, UNIVAC 1110, and IBM 360. A detailed user's manual was published [5].

1.4 Generalized Chain Coding

A major investigation pursued during the past year was concerned with the development of improved representation schemes for line-drawing data, especially geographic map data.

Probably the best-known and most widely used representation scheme for free-form line drawings (e.g., terrain contour maps, weather maps, plots of isophotes, flow patterns, etc.) is the so-called chain code [14]. Its popularity is generally attributed to a combination of its elegant simplicity, ability to yield to powerful processing algorithms, compactness and versatility [15]. During the past year a study was undertaken to generalize the concept of the 8-direction chain and to determine whether line-drawing representation schemes could be realized that would be superior in terms of compactness, precision (for a given grid size), smoothness, facility for processing, and ease of encoding.

The standard chain code represents a curve by means of a string of straight-line segments of two lengths, T and $T\sqrt{2}$, where T is the assumed grid spacing and can be made arbitrarily fine. The straight line segments connect 8-adjacent nodes on a square lattice. The possibility of considering grid nodes beyond those having the 8-adjacent property has been considered in the past; however, it was not explored in depth because of its apparent complexity and the lack of any clear advantages. Recent work [16] has shown that using nodes with distances of

$3\sqrt{2}$ and even $4\sqrt{2}$ offers some exciting possibilities in overall representation efficiency.

Although the higher-order coding schemes involve more effort when encoding a given line drawing and lead to somewhat more complex processing algorithms they permit more compact representation. Since they include longer-length links, fewer links will, in general, be required, reducing the number of calls on the processing subroutines (and thus in part compensating for the increased complexity of these subroutines). Since for well-quantized chains, the probability of occurrence of a particular chain link decreases with increasing angular difference relative to the previous chain link, the reduced number of total links also leads to significantly reduced storage requirements. Finally, and perhaps most important, the increased angular resolution offered by the higher-order chain code matrices permits the achievement of both higher precision and improved smoothness of curvature.

1.5 Line-Drawing Processing Language, CHAP

To facilitate the work in line-drawing processing and map data analysis, a large set of analysis and manipulation algorithms was assembled into a special line-drawing processing language called CHAP [3,6]. The language was subjected to considerable testing during the past year. A version for use on an IBM 360/370 system is now available for release. Versions for UNIVAC 1110 and CDC 6000 series computers are planned for the coming year.

1.6 Shape Classification

A key element in pattern recognition is the description of shape. For two-dimensional objects, shape is conveyed by the curving of the boundary lines defining them and is normally regarded as being independent of scale and orientation. One of the difficulties in any shape processing task is the lack of a definitive way of describing shape. The contour whose shape is desired can be represented in the chain code. However, the chain code representation does not explicitly display the features we normally regard as characterizing shape, and a more explicit shape description scheme is needed.

A study for an effective shape description scheme was started during the past year. The approach followed was to segment a given contour at so-called critical points - points that with varying degrees of confidence, could be reliably identified. These are discontinuities in curvature, intersections, points of inflection, curvature maxima, and curve endings. The last-named are normally the least dependable because the ending may depend on a section of a curve being occluded by another object or lost in the process of extracting the contour from a photographic image. Then for each segment a set of scale- and orientation-invariant features may be calculated and these used to characterize the shape of the contour segment. Where appropriate, precise shape matching or fitting may then be carried out using a curve correlation technique [15].

For the foregoing technique to be effective, good procedures must be available for extracting the critical points from a chain-coded curve, in spite of the presence of quantization noise. Some excellent progress toward this objective was recently made, especially with regard to the extraction of curvature discontinuities and points of inflection [4]. These two kinds of critical points can be detected by means of a scanning line segment which traces out the contour while joining the end points of two chain links spaced about 5 to 8 links apart. (The exact spacing depends on the anticipated noise in the contour and the fineness with which the contour has been quantized.) The variation in the angular difference is then monitored as the segment traces out the contour. At a curvature discontinuity ("corner"), a characteristic, rapid variation in the angular difference is detectable. At a pronounced point of inflection, there is a sharp change of sign in the angular difference. Slow, "meandering" kinds of inflections can, of course, not be detected in this way; they would in any case be unreliable.

2. PUBLICATIONS

1. M. Potmesil, "An Implementation of the Loutrel Hidden-line Algorithm." Tech. Report CRL-49, Rensselaer Polytechnic Institute, Troy, New York, 62 p., September 1976. (AD-A036 401)

Abstract: This report describes an implementation of a variation of the hidden-line algorithm developed by P. Loutrel. The new algorithm produces hidden-line drawings of scenes composed of opaque polyhedra as well as of some more general types of flat-faced objects not covered by the original Loutrel algorithm. The program is written in Fortran IV and has been implemented in a batch version on a CDC 6600 computer and in an interactive version on an ADAGE AGT-30 interactive graphics computer.

2. H. Freeman, "Automatic Data Processing Techniques for Graphic-Data Display, Generation and Analysis". Tech. Report CRL-50, Rensselaer Polytechnic Institute, Troy, New York, 27 p., October 1976. (AD-A033 315)

Abstract: This Interim Technical Report summarizes the research carried out under Grant AFOSR 76-2937 during the period 1 September 1975 - 31 August 1976. The research activities were concerned with three distinct problem areas: (1) the development of efficient algorithms and heuristic techniques for the reconstruction of three-dimensional scenes from multiple photographs, (2) the study of improved coding schemes for line-drawing data, especially topographic maps, and (3) the development of thoroughly tested computer programs for eliminating the "hidden" lines in perspective views of complex planar-faced and quadric-surface-face objects. The individual research areas are briefly described and abstracts of the publications issued during the reporting period are given.

3. H. Freeman, J. Paolicelli, and M. Potmesil, "Programmer's Manual for the CHAP Line-Drawing Processing Language". Tech. Report CRL-52, Rensselaer Polytechnic Institute, Troy, New York, 82 p., December 1976. (AD-A036 391)

Abstract: This report describes CHAP, a computer language for processing line drawings represented in terms of the 8-direction chain code. The language consists of a set of FORTRAN subroutines, most of which are machine independent. The subroutines may be called by a user program to accomplish specific line-drawing processing tasks. The chain data is stored in packed (machine-dependent) form and is unpacked for processing. The report lists all currently available CHAP subroutines and provides all necessary information for a CHAP programmer. Specific information for different machine implementations are given in the appendices. Thus far an implementation exists only for an IBM 360 computer. However, implementations for UNIVAC 1108/1110, CDC 6600, and ADAGE AGT 30/130 are presently being planned.

4. H. Freeman, "Shape Description via the Use of Critical Points", Proc. IEEE Conference on Pattern Recognition and Image Processing, IEEE publ. 77CH1208-9C, June 6-8, 1977, pp. 168-174. (AD-A040 273)

Abstract: A key element in pattern recognition is the description of shape. For two-dimensional objects (blobs), shape is conveyed by the curving of the boundary line and is normally considered independent of scale and orientation. The curving may be regarded as a concatenation of arcs of varying instantaneous radii of curvature, possibly interspersed occasionally by discontinuities. The description of shape is facilitated by segmenting the boundary line at so-called critical points - corners (discontinuities in curvature), points of inflection, and curvature maxima. Additional critical points are intersections and points of tangency. Algorithms are described for extracting such critical points in the presence of noise. An illustration is given showing how the critical points may be used in the development of a shape description system.

5. M. Potmesil, "QUADRAW User Manual", Tech Report CRL-53, Rensselaer Polytechnic Institute, Troy, New York, 75 p., June 1977.

Abstract: This report is a user manual for the program QUADRAW which draws visible-line-projection pictures of objects bounded by sections of quadric surfaces. The report describes three versions of the program, one each for the CDC 6600, Univac 1110 and IBM System 360-370 computers. It also provides the necessary documentation to permit one to modify the program for any other computer.

6. H. Freeman, J. Paolicelli, and M. Potmesil, "Programmer's Manual for the CHAP Line-Drawing Processing Language", Tech. Report CRL-52A, Rensselaer Polytechnic Institute, Troy, New York, 82 p., Revised June 1977.

Note: This is a revised and up-dated version of Tech. Report CRL-52.

Abstract: This report describes CHAP, a computer language for processing line drawings represented in terms of the 8-direction chain code. The language consists of a set of FORTRAN subroutines, most of which are machine independent. The subroutines may be called by a user program to accomplish specific line-drawing processing tasks. The chain data is stored in packed (machine-dependent) form and is unpacked for processing. The report lists all currently available CHAP subroutines and provides all necessary information for a CHAP programmer. Specific information for different machine implementations are given in the appendices. Thus far an implementation exists only for an IBM 360 computer. However, implementations for UNIVAC 1108/1110, CDC 6600, and ADAGE AGT 30/130 are presently being planned.

7. R. Shapira and H. Freeman, "Reconstruction of Curved-Surface Bodies from a Set of Imperfect Projections", Proc. 5th Int'l Joint Conf. Artificial Intelligence, publ. by Dept. of Computer Science, Carnegie Mellon Univ., Pittsburgh, Pa. 15213, August 1977, pp. 628-634.

Abstract: A procedure is described for obtaining the description of solid bodies from a set of pictures taken from different vantage points. The bodies are assumed to be bounded by faces which are planar or quadric, and to have vertices formed by exactly three faces. The line and junction information provided to the program by the preprocessor is assumed to contain defects such as missing lines or wrongly classified junction types. The procedure is able to build a description of the bodies in spite of a moderate number of such imperfections. Use is made of a set of new grammar rules for line-drawing projections of curved and planar bodies.

8. R. Shapira and H. Freeman, "A Cyclic-Order Property of Bodies with Three-Face Vertices", IEEE Trans. Computers, C-26, (10), October 1977.

Abstract: A cyclic-order property is defined for three-dimensional bodies with vertices formed by three faces. The property is useful in resolving ambiguities caused by the extraction of imperfect line data from photographs of such bodies. The property augments the grammatical rules that govern the possibility or impossibility of the existence of three-dimensional bodies corresponding to particular two-dimensional line-structure projections.

9. R. Shapira and H. Freeman, "Computer Description of Bodies Bounded by Quadric Surfaces from a Set of Imperfect Projections. Accepted for publication in <u>IEEE Trans. on Computers</u>.

<u>Abstract</u>: This paper describes a computer program for constructing a description of solid bodies from a set of pictures taken from different vantage points. The bodies are assumed to be bounded by faces which are planar or quadric, and to have vertices formed by exactly three faces. It is assumed that a preprocessor provides the program with line and junction information which it has extracted from the pictures. The preprocessor is expected to make mistakes, such as losing features or providing misinformation about their nature. A technique is presented for validating doubtful features as well as for matching corresponding features extracted from the different pictures. New grammar rules are developed for line-drawing projections of curved and planar bodies and are used as a tool in the scene analysis process. Each picture's data analysis is supported dynamically by the results obtained thus far in the other pictures' analysis. The analyzed data from all pictures are grouped into sets, each corresponding to a single face (flat or curved), whose nature is also determined. The sets are grouped again to correspond to the different bodies in the scene. The program written in PL/I has been tested successfully on several scenes.

10. R. Shapira and H. Freeman, "The Cyclic Order Property of Vertices as an Aid in Scene Analysis". (Submitted for publication in Communications of ACM)

Abstract: A cyclic-order property is defined for bodies bounded by smooth-curved faces. It is shown to be useful in analyzing pictures of such bodies, particularly when the line data extracted from the pictures is imperfect. This property augments previously known grammatical rules that determine the existence of three-dimensional bodies corresponding to given two-dimensional line-structure data.

3. PRESENTATIONS

Invited presentations by Principal Investigator:

1. "Computer Assembly of Jig-Saw Puzzles", ACM lecture, RPI, 18 November 1976.

2. "Some Recent Advances in Line-Pattern Coding Schemes", Computer Science Seminar, The University of Rochester, Rochester, New York, 13 December 1976.

3. "Computer Graphics", Conference of the Society of Engineers of Eastern New York, Union College, Schenectady, New York, 25 January 1977.

4. "Computer Interpretation of a Three-Dimensional Scene", Colloquium lecture, Ecole Nationale Superieure des Telecommunications, Paris, France, 15 March 1977.

5. "Some New Coding Schemes for Contour Map Data", Seminar lecture, Gesellschaft für Mathematik und Datenverarbeitung, Bonn, Germany, 16 March 1977.

6. "Algorithms for Digital Map Data Processing and Scene Analysis", invited lecture, Conference on Automatic Map Data Processing and Related Techniques, Cosenza, Italy, 21-22 March 1977.

7. "Implementation of Hidden-Line Algorithms", Adage Graphics Exchange meeting, Washington, D. C., 16-17 May 1977.

4. REFERENCES

For Items 1 through 10, see the section titled PUBLICATIONS, where complete abstracts of these publications are given.

11. R. Shapira, "Computer Reconstruction of Bodies Bounded by Quadric Surfaces from a Set of Imperfect Projections", Tech. Rept. CRL-48, Rensselaer Polytechnic Institute, Troy, N. Y. 12181, September 1976, 116 p. (AD-A035 563).

12. P. Loutrel, "A Solution to the Hidden-line Problem for Computer-Drawn Polyhedra", IEEE Trans. Computer, C-19, (3), March 1970, 205-213.

13. P. Woon, "A Computer Procedure for Generating Visible-line Drawings for Solids Bounded by Quadric Surfaces", Tech. Rept. 403-15, doctoral dissertation, Department of Electrical Engineering, New York University, Bronx, N. Y., December 1970 (AD-724 744).

14. H. Freeman, "On the Encoding of Arbitrary Geometric Configurations", IRE Trans., EC-10, (2), June 1961, 260-268.

15. H. Freeman, "Computer Processing of Line Drawing Images", Computing Surveys, 6, (1), March 1974, 57-97.

16. H. Freeman, "Analysis of Line Drawings", Proc. NATO Advanced Study Institute on Image Processing, Bonas, France, 1976.

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20. ABSTRACT (Continued)

programs for the removal of "hidden lines" from the projection of both planar-faced and quadric-surface objects, (3) the design of a generalized chain coding scheme for the compact and precise description of map data, (4) the development of a line-drawing processing language, (5) an investigation into some new approaches to scale- and orientation-independent shape classification.